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Electricity pricing algorithm based on resource type and nodal approach

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ABSTRACT

The aim of the electrical system operators is to ensure that energy is delivered to the consumer in good quality and without interruption. The main purpose of the electricity market operators is to provide the electricity to the end user as adequate, continuous and low cost. Demand for energy in the world is constantly increasing due to technological developments, increasing world population and welfare of people. The lower cost of electricity will lead to a higher quality of life and a more competitive condition in the industry [1-3]. For this reason, the cost of electricity is very important for everyone. While revealing the price of electricity, many different data are taken into account. These are generation, transmission and distribution costs. Generation costs include such as initial investment, operation, and supply costs. Depending on the source used, electric energy can be generated at very different costs. Transmission costs include investment and operation costs of substation centers and transmission lines used in the transmission system. Distribution costs are the operation and investment of the distribution system and the expenditures of some ancillary services delivered to the end user.

Electricity prices are offered to end users with specific tariffs. However, these tariffs are disadvantageous for some users. Because, in the calculations made, the type of production source or the geographical location of the plant are not considered [4]. Therefore; for both producers and consumers, it is thought that these calculations can be made in a more acceptable way, taking into account the location of the source of production in the system and the interconnected system.

1. Introduction

In an electrical system, it is also aimed at ensuring the continuity, safety and regeneration of energy while being economical. As much as possible, fair and realistic prices should be determined to provide electricity to the consumers economically. To achieve this realistic approach, the energy production cost and the transmission cost should be reflected separately in the prices. It should not apply the same price tariff to a consumer who is fed from a factory with a relatively low production cost and a factory with a higher production cost. Manufacturers and consumers will set their investment positions in the electrification system with these different pricing options that can be offered to them [5-8]. The system will achieve a homogeneous structure with different prices to be produced in different buses of the interconnected system. Otherwise, production facilities will be gathered in one part of the system; the consumption facilities will be collected in another region. This will cause unnecessary financial burdens in the country's economy with long transmission lines and transformer centers that need to be set up. In the present case, in some regions of the electrification system there are transformers or installed power capacities waiting in idle, while overloading problems are encountered on the other side. In order to avoid this situation, users can be directed to more economical parts of the system with pricing algorithms. For example, for a company that wants to set up a new generation facility in an area with more generation facilities, the generation price in that area would be lower than in other regions, thus encouraging the establishment of a generation facility in other possible locations. In the same way, a user with energy demand in areas where heavily consumed (for large subscriptions such as the Organized Industrial Zone fed from the Transmission System) could plan an investment in a region where the electricity cost would be

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more economical because the electricity costs in this region will be higher than in other regions.

For each generation facility that is a market participant; a calculation to be made considering factors such as the type of energy source, the position of participating in the generation, the size of the installed power, etc. may result in more realistic results. The different costs that arise in different parts of the interconnection system must be reflected to the energy demand consumer [9-11]. With this approach, the cost can be calculated according to the area to be connected on the interconnected system.

There are no articles in the studied studies that are calculated according to the production source type. From this point of view, this article presents an innovative approach. Another innovation introduced in the proposed pricing algorithm is the multi-stage dynamic programming method used. This method is able to obtain multiple solution functions in a way not previously implemented in Dynamic Programming.

In the first part of the work, information on the importance of Electricity Pricing methods and the method applied is given. This method will be explained benefits in terms of users and in terms of the transmission system. Then, a brief description will be given about the structure of the electricity market in Turkey. In the third part, information about pricing algorithms will be given and details of the pricing algorithm suggested in the last section will be determined. The proposed pricing algorithm will be tested on the IEEE-30 busbar test system and the sample balanced busbar system. Benefits will be evaluated in the last section compared to other methods applied.

2. Structure of Electricity Market in Turkey

After starting in 1902, the first electricity production, electricity sector in Turkey is advancing constantly and quickly. In 1970 (Turkey Electricity Authority) was established and electricity transmission, distribution, production and trade are given tasks. In 1984 private companies were allowed to generate electricity. In 1993, TEK, TEAS and TEDAŞ were divided into two. In 2003 TEAS, TEİAŞ, EÜAŞ and TETAŞ were divided into three divisions. TEİAŞ, as a public institution (Turkey Electricity Transmission Company) engages in electricity transmission tasks. TEDAŞ (Turkey Electricity Distribution Company) is divided into 21 regions and distribution tasks are managed by private companies.

EMRA (Energy Market Regulatory Authority) was established in 2001. In 2013, transmission system operation and market operation are separated. EPIAS (Energy Market Operational Company - EXIST) was established for the market operation. As a result of these developments, the electricity energy market has become more flexible and all participants have shaped as shown in Table 1.

Table 1 The Occurrence Process of Turkish Electricity Market

Before 1993	TEK				
1993-2003	TEAŞ			TEDAŞ	EPDK
2003-2015	TEİAŞ	EÜAŞ	TETAŞ	21 Dist. Co.	
After 2015	TEİAŞ	EÜAŞ	TETAŞ	21 Dist. Co.	EPİAŞ

Resources used in electricity generation in Turkey can be listed as Natural Gas, Hydroelectric, Coal (Domestic and Import), Wind, Solar, Geothermal, Biomass and Nuclear (in the near future) energy. These sources are used in generation facilities that supply energy to the system from different points of the national interconnection system. This actually means that different costs are created in different regions. At present, the installed capacity of Turkey is 80.000 MW and annual consumption is 285.000 GWh for the year 2017. The national electricity network has approximately 800 down-center (transformer center) and more than 60,000 km energy transmission lines. The distribution of these lines and transformer centers on the interconnected system is not homogeneous in the present case. For instance in Thrace and Western Anatolia, the density of industry is high but generation is low, consumption in Eastern Anatolia is very small, but energy generation is quite high. In addition to the many different reasons underlying this situation, one of the reasons is the applied electricity pricing methods.

With the new price tariffs that are introduced, different prices can be offered to the consumers according to the regions. Consumers will be able to obtain the electric energy more economically by determining the production resource type and location [12]. This will affect prices positively. As a side benefit, the electrification system of the country will become a homogeneous structure.

3. Pricing Algorithms

As pricing approaches; it can be said that there are three main approaches, namely, Price Based Pricing (PBP), Competitive Based Pricing (CBP) and Demand Based Pricing (DBP). PBP, can be divided into "cost plus" and "target price". The method which is calculated by calculating fixed costs and variable costs and adding the targeted profit ratio is called "cost plus". The pricing that is calculated by calculating the profit to be obtained in a certain sales volume is defined as "Target Pricing" [13-16]. CBP is divided into two parts as "Market Price Based" and "Tender Procedure". The method of determining its own price on the current price in the market is called "Market Price Based". It is known as the "Tender Procedure" or the closed envelope method, and the price is estimated without knowing the price of the rival. On the other hand, DBP is based on the methods of price determination according to customer, time, time and product. Due to the characteristic of electric energy and being the only product on the market, the PBP-based pricing approach is considered as the most appropriate method. Here, the price of the product should be determined taking into consideration any of the cost value, investment value and sales value. So, in general, the method known as "Cost Plus" is chosen.

Energy resources are divided into renewable and non-renewable energy sources according to their use. According to its convertibility, it is divided into primary and secondary energy sources. Energy that is not converted to any energy is called primary energy. The energy obtained after the transformation of the primary energy is defined as secondary energy. Primary energy sources are oil, coal, natural gas, nuclear, hydraulics, biomass, wave, tide, sun and wind. Secondary energy sources are electricity, gasoline, diesel, coke, secondary coal, petroleum coke, air gas, liquefied petroleum gas (LPG). Renewable energy sources are energy resources which cannot be consumed in a natural cycle and which do not decrease [17-20]. Hydraulics, solar, wind, biomass and wave are sources of renewable energy. Non-renewable energy sources are energy sources that cannot renew themselves once they are used. Core energy sources such as oil, coal, natural gas and uranium, thorium are non-renewable energy sources.

As mentioned in the first section, there are different calculation methods for calculating the costs of production plants. The main determining factor here is the type of resource used by the plant. The cost of each plant depends on its own fuels, operation and plant costs. The average cost of electricity production of the most important sources in Turkey and percentage of production is shown in Table 2. The values given in this table were obtained from different studies prepared by the World Energy Council (WEC).

Table 2. Resources, Costs and Generation Contribution Rates.

Type	FIC (TL/kW)	FOC (TL/kW-year)	VOC (TL/kWh)	PTP (%)
Coal	16.362	189,45	20,7	144,9
Natural Gas	4.401	49,5	15,75	161,1
Nuclear	26.752,5	451,26	10,35	-
Wind	8.446,5	178,65	-	27,9
Solar	12.019,5	105,3	-	-
Biomass	22.432,5	495	18,9	3,6
Hydro	13.212	63,59	-	104,85
Geothermal	7.038	83,7	10,8	7,65

FIC: First Investment Cost
FOC: Fixed Operation Cost
VOC: Variable Operation Cost
PTP: Percentage of Total Production

There are various calculation methods for calculating **the cost of the transmission system**. The costs associated with the transmission system are generally regarded as operating and maintenance costs of energy transmission lines and transformer centers. The most common pricing method that can be shown using these costs is "Investment Cost Based Pricing" (ICBP). This method is used in Turkey and many world countries [21-23]. When calculating the transmission cost, power losses are also taken into account, depending on the lengths and characteristics of the transmission lines.

4. Multi Stage Dynamic Programming

There are two main elements of the price list prepared for transmission system users. Production and transmission cost. Determination of Production Cost: Firstly, other production facilities connected to the reference bar should be identified. Then, the type and loading rates of the resources used by these production facilities should be known (Table 3.). The load flow analysis data of the other plants in the rear will be included dynamically (with certain periods) in the calculations.

Table 3. **C**haracteristic information of the plants in the sample bus bar system.

	Resource Type	Installed Power [MWe]	Offer Price [TL/MWh]	Production Amount [MW]	Capacity Factor (%)
1	Coal	400	216	400	88
2	HPP	1000	182	900	86
3	WPP	130	190	100	32
4	Nat. Gas	600	204	400	93
5	Coal	720	183	600	91
6	WPP	310	211	200	28
7	SPP	180	194	100	21
8	HPP	800	188	700	80
9	HPP	330	200	300	91
10	Nat. Gas	1000	199	800	96
11	Coal	550	201	300	83

Determination of transmission cost: Transmission lines and other transformer centers (lines with positive energy flow) in the transformer center to which the consumer is connected are determined. In addition to the production facilities in the bar, the costs of the loads coming from the other transformer center are included in the account like a production facility. In addition, the transmission cost is determined by considering the characteristic, cross-section, length of the connection lines (Table 4.). The transmission cost coefficient is obtained according to the loading rates of the connected energy transmission lines. In power transmission lines, the power losses to be calculated according to the load flow are also calculated. The cost of transmission lines and transformers installed by the transmission system operator will be included in the tariff locally [24-25].

Table 4. Characteristic information of energy transmission lines in the sample bus system.

Label	Conductor Cross-Section	Conductor Length	Load Flow	Constraint State
1-2	1272 MCM	43 km	200 MW	None
1-5	954 MCM	72 km	200 MW	None
1-4	1272 MCM	130 km	200 MW	None
1-6	2x1272 MCM	62 km	200 MW	None
6-5	954 MCM	29 km	100 MW	None
4-5	1000 mm^2 cable	12 km	300 MW	None
5-11	1272 MCM	64 km	100 MW	None
6-3	477 MCM	28 km	200 MW	None
3-2	1272 MCM	110 km	900 MW	None
3-7	795 MCM	96 km	500 MW	None
6-9	954 MCM	64 km	200 MW	None
9-11	477 MCM	43 km	100 MW	None
9-8	2x954 MCM	74 km	900 MW	None
8-7	1272 MCM	210 km	800 MW	None
8-10	2x1272 MCM	38 km	0 MW	Yes
9-10	954 MCM	57 km	100 MW	None

A small section of the transmission system can be considered to illustrate the operation of the design. It is seen here that the system is balanced in terms of loads and production facilities. This is because when the entire transmission system is taken into consideration, a balance state will be discussed. There are 11 bus bars and 16 energy transmission lines in the system part taken as a section here. There is 4900 MW of total production in the bus bars. The instantaneous load flow of this system also appears in Figure 1. A bus bar selected as reference and will be calculated price on this bus bar. According to the step-by-step solution technique of Dynamic Programming, stages are determined starting from the reference bus bar.

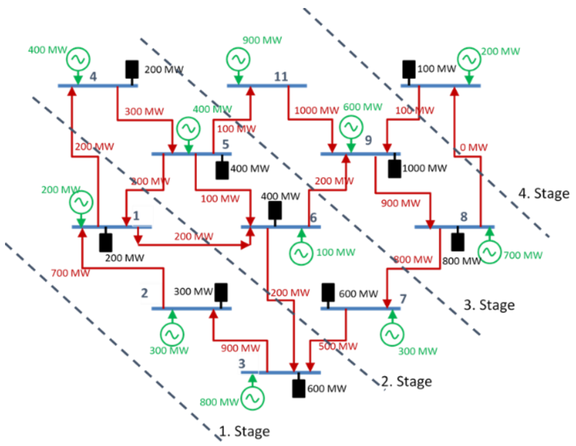

Figure 1. Balanced section of the interconnected system

The bar number 10 was chosen as the reference bar. From this point on, a four-stage calculation will be made. In the fourth stage, the reference bars own production and consumption (COPC) are calculated in Equation 1.

$$F_4(10) = COPC\ [TL/MWh]$$

$$COPC = CP_{TL} \div (TPP - TCP)_{MW}\ (per\ hour)\quad [TL/MWh] \qquad (1)$$

COPC: Cost of Production and Consumption

TPP: Total Production Power

TCP: Total Consumed Power

CP: Cost of Production

In the third stage; the costs of bars 9, 8 and 11 to the reference bar are calculated. Appropriate functions are written for the other bars in the generated steps. These functions are given in the equations 2,3 and 4.

$$F_3(9) = min \begin{cases} \dot{I}_{8-9} + F_3(8) \\ \dot{I}_{9-10}\, COPC \end{cases} [TL/MWh] \qquad (2)$$

$$F_3(8) = \dot{I}_{8-10}\, COPC\quad [TL/MWh] \qquad (3)$$

$$F_3(11) = \dot{I}_{11-9}\, COPC + F_3(9)\quad [TL/MWh] \qquad (4)$$

In the second stage; costs of bars 7, 6, 5 and 4 are calculated on the way to the reference bar. These functions are given in the equations 5,6,7 and 8.

$$F_2(7) = \dot{I}_{7-8} COPC + F_3(8)\quad [TL/MWh] \qquad (5)$$

$$F_2(6) = min \begin{cases} \dot{I}_{6-9}\, COPC + F_3(9) \\ \dot{I}_{6-5}\, COPC + F_2(5) \end{cases} [TL/MWh] \qquad (6)$$

$$F_2(5) = min \begin{cases} \dot{I}_{5-11} COPC + F_3(11) \\ \dot{I}_{5-6} COPC + F_2(6) \end{cases} [TL/MWh] \qquad (7)$$

$$F_2(4) = \dot{I}_{4-5}\, COPC + F_2(5)\quad [TL/MWh] \qquad (8)$$

In the first stage; the costs of cars 3, 2 and 1 on the way to the reference bar are calculated. (Equations 9,10 and 11)

$$F_1(3) = min \begin{cases} \dot{I}_{3-7}\, COPC + F_3(7) \\ \dot{I}_{3-2}\, COPC + F_1(2) \\ \dot{I}_{3-6}\, COPC + F_2(6) \end{cases} [TL/MWh] \qquad (9)$$

$$F_1(2) = min \begin{cases} \dot{I}_{2-3} COPC + F_1(3) \\ \dot{I}_{2-1}\, COPC + F_1(1) \end{cases} [TL/MWh] \qquad (10)$$

$$F_1(1) = min \begin{cases} \dot{I}_{1-2} + F_1(2) \\ \dot{I}_{1-5} + F_2(5) \\ \dot{I}_{1-6} + F_2(6) \\ \dot{I}_{1-4} + F_2(4) \end{cases} [TL/MWh] \qquad (11)$$

Same way, the similar functions are calculated for different stages selected towards the direction of the other bus bars to which the reference bus bar is connected. The price of the reference bus bar is determined by selecting the most economical one among the results obtained from all these functions.

A flow chart is used to create the steps shown above and to reveal the functions. The flow chart of the process followed to determine the tariff of the reference bus bar is given in Figure 2. In the flow chart, firstly the price targeted by the consumer needs to be determined. Since all the bus bars on the transmission system are numbered separately, the formulas are executed on these numbers. Then it will be determined which bus bar price to calculate (reference bar). Then production facilities and consumption facilities connected to the reference bus bar has been determined. Load Case Analysis for the total installed capacity, capacity factor, resource type and related period interval of the production facilities is revealed. Capacity information is also obtained for consumption facilities. Then, the energy transmission lines connected to this bar and the length of these lines, cross section (if section changes), transport capacities and limit conditions of the line are determined.

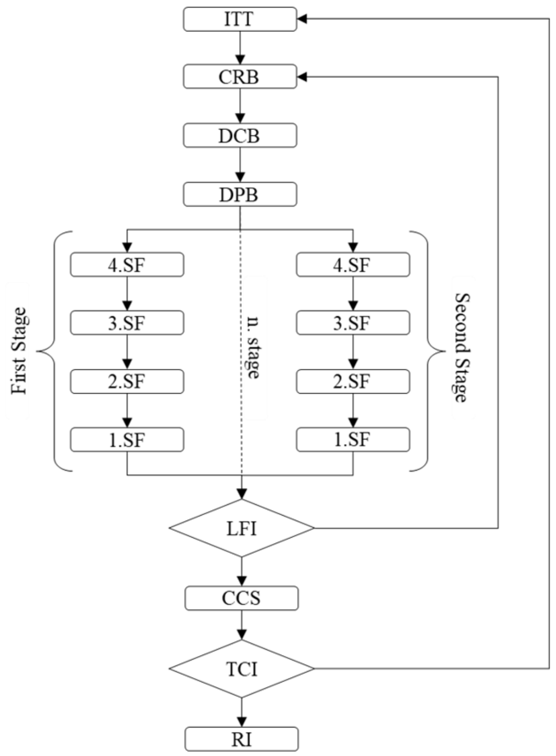

Figure 2. Multi Stage Dynamic Programming Algorithm Flowchart

After this phase, the first stage path is determined backward from the relevant bar. First, the bus bar closest to the reference bus bar, then the other bus bar connected to this bus is identified. This is continued until the fourth stage. At the same time, considering the other bar that is connected to the reference bar, it moves again to the fourth step in a different direction. After all stages are completed on all possible routes, the calculations obtained are compared. Before determining the most advantageous stage path, it is checked whether there are any restrictions on the load flow and the characteristics of the line. If there are constraints, the calculations are repeated in a way that this constraint permits. If there is no constraint or is included in the calculations, the pricing formulas are reached [26-28]. After this phase, the actual values obtained for the production facility and the values from the tariffs for the transmission lines are written in the formulas to obtain the optimum energy price for the reference bar.

The details of the process at each step of the flow chart can be explained as follows:

1. **I**dentification of **T**arget **T**ariffs: Calculation of the price the user expect to connect the system
2. **C**hoice **R**eference **B**ar: Selection of the Reference Bar
3. **D**etermination of **C**onsumers in the **B**ar: Calculation of usage capacity of other consumers in bar
4. **D**etermination of **P**roducers in the **B**ar: Calculation of installed capacity of other producers in bar
5. n. **S**tage **F**unctions: Determination of stages and obtaining functions for each stage. (For each direction)
6. **L**oad **F**low **I**nquiry: If available Y, If not available N: Checking the suitability of the connection for load flow.
7. **C**ost **C**alculation for **S**ource: Calculation of electricity cost according to source type
8. **T**arget **C**ost **I**nquiry: Comparison of targeted and obtained price: If target price is less than cost Y, target price is greater than cost N.
9. **R**ealization of **I**nvestment

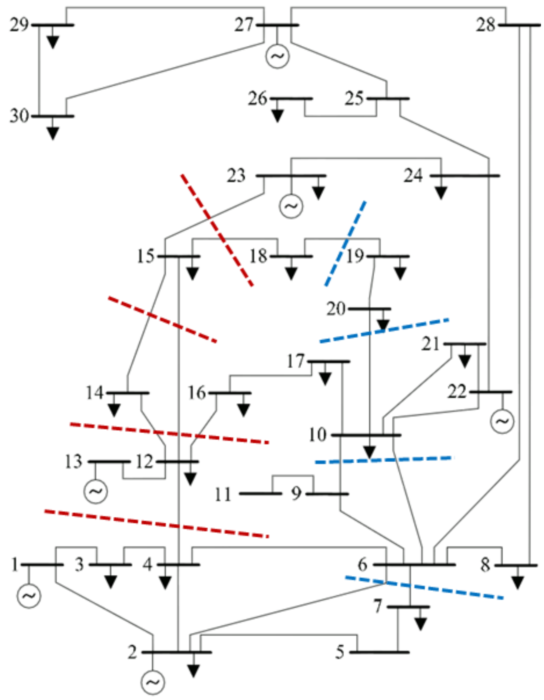

Figure 3. IEEE-30 (RTS) Bus Test System

The proposed pricing model has been tested on the IEEE-30 bar test system. Accordingly, the price function will be obtained for the bar number 18 selected as the reference bar. As shown in Figure 3, the MSDP model is run with the specified steps towards different routes. The final results of the obtained functions and the final prices are given in Table 5. There are also prices obtained from Balanced System Section (BSS) on the same Table. A comparison was made between the average price obtained from the current pricing method and the prices found. The error rate is shown in the same table. Accordingly, it can be said that the MSDP model offers more favorable prices for selected reference bus bars than the current situation.

Table 5. Comparison of the results of the MSDP model.

		MSDP [TL/MWh]	CPM [TL/MWh]	MAPE (%)
IEEE-30 RTS	First Stage	60.13		
	Second Stage	94.98		
	Third Stage	137.83		
	Fourth Stage	209.61	231.43	9.42
BSS	First Stage	53.76		
	Second Stage	86.12		
	Third Stage	138.28		
	Fourth Stage	190.54	211.91	10,08

5. Conclusions

There are many different pricing methods for transmission system users. Some of them accept the system as a whole and perform calculations accordingly. Some of them make different tariffs by dividing them into regions (Regional Pricing). Another approach is to calculate a separate price for each bus bar (Nodal Pricing). In this study, a different and new approach to the nodal pricing method has been introduced. Price calculation has been done according to production source type which was not taken into account in the literature before. Another innovation introduced is; it has been tried to achieve optimum functions by creating multiple stages in dynamic programming. The prices obtained from this new method, called Multi-Stage Dynamic Programming (MSDP), are compared with the prices obtained from the Conventional Pricing Model (CPM). For this comparison, a Balanced System Section (BSS) and IEEE-30 test system was used for the interconnected system.

According to the obtained data, the proposed method provides more realistic and economic prices for the users of the transmission system on a bus bar basis. With this new method, about 10% lower prices can be obtained for the users of the transmission system than the prices calculated by the conventional method. This new price tag, which is achieved without change in the total revenue cap, is expected to provide considerable advantages for users. The MSDP method, which is advantageous for transmission system users, will also ensure that the transmission system becomes homogeneous in the long run.

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